LCA Concepts and Methods

Life Cycle Assessment of Contaminated Sites Remediation

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Abstract

For the federal state of Baden-Württemberg, Germany, the decision tool "Umweltbilanz von Altlastensanierungsverfahren" has been developed and found suitable for the quantification and evaluation of environmental impacts caused by remediation of contaminated sites. The developed tool complements the remediation toolbox of Baden-Württemberg. The tool includes a streamlined life cycle assessment (LCA) and a synopsis of the LCA results with the results of a risk assessment of the contaminated site. The risk assessment tool is not explained here. The data base for the life cycle inventory includes several techniques used in remedial actions. The life cycle impact assessment utilises 14 impact categories. The method allows comparisons between remedial options for specific contaminated sites. A software tool has been developed to be available in 1999.

Keywords: Comparisons; contaminated sites; dirty diesel scenario; environmental management; environmental policy instruments; in-situ bioremediation; life cycle assessment; life cycle impact assessment; life cycle interpretation; life cycle inventory analysis; remediation; risk assessment; software tools

1 Introduction

1.1 Planning of remedial actions

JOZIASSE and co-workers (1998) and DIAMOND (1998) apply life cycle assessment to the remediation of contaminated sites. These studies are restricted to selected remediation cases.

BEINAT and co-workers (1997) developed a decision tool (REC) integrating many options in making remediation. Our approach (this work) also includes many remediation techniques, but has a more detailed life cycle assessment approach than the Dutch REC method. While REC includes the conduction of a risk assessment, our approach includes only the results of a risk assessment. The REC method also considers costs which are not considered in our approach. The removal of toxic substances is part of the life cycle assessment of the REC method. Therefore, the REC method can be used to identify a suitable clean up level. Our method requires the definition of the clean up level before starting the software calculations and is therefore only suitable for the selection of different remediation options for specific cases (those with a predetermined clean up level).

Preliminary descriptions and case studies of our method have recently been published (VOLKWEIN et al., 1997, 1998; BENDER et al., 1998; NJIBOER and SCHELWALD-VAN DER KLEY, 1998).

In Baden-Württemberg the requirements for the selection of remedial action techniques are regulated by the administrative guideline "Orientierungswerte". Economic and environmental aspects have to be considered in the regular weighting process. In Baden-Württemberg, the evaluation of the environmental aspects until now includes only a risk assessment of the contaminated sites. The risk assessment estimates the polluted mass of the contaminated soil and water, examinates the danger of spreading the toxic substances, and evaluates the hazard for men, animals and plants. These primary impacts do not consider the negative potential environmental impacts ("secondary impacts") caused by the remediation itself. The new method has the task of complementing the risk assessment of the primary impacts with an evaluation of secondary impacts. The project "Modellvorhaben Sinsheim" contained one subproject to develop a method for the evaluation of these secondary impacts. The life cycle assessment approach is used to evaluate the secondary impacts.

This method is not intended to be used in every remediation plan. A presupposition is the necessity of the remedial action. The method is designed for those cases of remediation planning with more than one financially, legally, and technically possible remediation option. The interface "synopsis" of the life cycle assessment and a risk assessment is used to further the final decision making. The risk assessment approach of Baden-Württemberg and the final decision making approach about the technical remediation are outside of the scope of this paper.

1.2 Modellvorhaben Sinsheim

The project "Modellvorhaben Sinsheim" took place from 1994 to 1998. The site of the former company Reinig (application of wood preservatives) has been remediated (onsite ensuring). A software tool "Umweltbilanz für Altlastensanierungsverfahren" including a streamlined life cycle assessment has been developed by the C.A.U. GmbH. **Table 1** shows the consortium of the Modellvorhaben Sinsheim.

Table 1: Development of the method "Umweltbilanz von Altlastensanierungsverfahren" within the project "Modellvorhaben Sinsheim"

Modellvorhaben Sinsheim	Institution, company
Contractor	Stadt Sinsheim (Baden-Württemberg, Germany)
Developer	C.A.U. GmbH
Consortium	Landesanstalt für Umweltschutz Baden-Württemberg (Karlsruhe),
	Landesgesundheitsamt Stuttgart,
	Technologieberatung Grundwasser und Umwelt GmbH (Koblenz),
	Landratsamt Rhein-Neckar-Kreis (Heidelberg), Gewerbeaufsichtsamt Mannheim,
	Geologisches Landesamt Baden-Württemberg (Freiburg),
	Regierungspräsidium Karlsruhe, Umweltbundesamt Berlin,
	Gesundheitsamt Heidelberg, Stadt Sinsheim

1.3 Method

The method consists of

- a streamlined life cycle assessment,
- an improvement assessment, and
- a synopsis of primary and secondary impacts.

2 Goal and Scope Definition

2.1 Functional unit

The definition of the functional unit is simple in order to allow a non-LCA expert to use the tool. The functional unit is the ensemble of activities to achieve a certain risk level (after the remediation). In Baden-Württemberg, the risk level after remediation is usually the level 4 of the "Maßgebliches Risiko" (Umweltministerium, 1987). The risk assessment tool is a separate tool not incorporated in the tool described here. The compared remediation alternatives perform the same functional unit if the goal risk level is achieved. The differences between the options beyond the risk level are not addressed within the life cycle assessment, but can be considered in the primary impacts.

2.2 System boundaries

The software contains a data bank of about 50 standard unit processes ("Module"). Every remediation option is modelled with these standard unit processes. In some standard unit processes the software user can change the preselected emission data.

The nuisances (odour, noise, human toxicity) for the inhabitants of the contaminated site or the neighbours is analysed. All direct emission occurring on the site and at 250 meters (m) distance to the site are attributed as "near emissions". For this reason, the number of arrivals of trucks and cars on the site with respect to the transport distance in the near emission range is counted separately. **Figure 1** shows the near emissions concept.

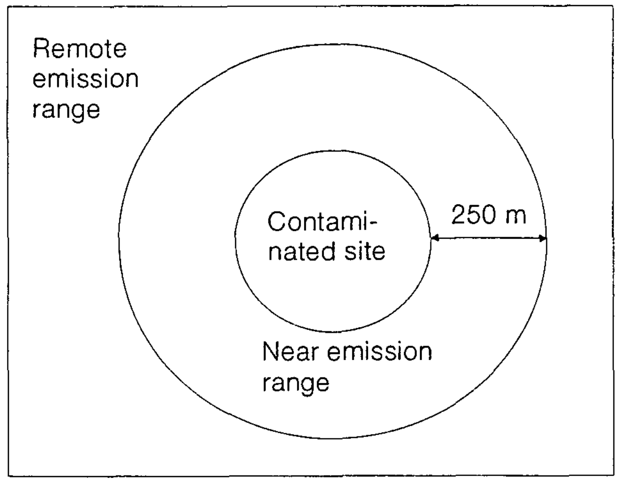

Fig 1: Near emissions concept for the remediation of a contaminated site

2.3 Data categories

The major headings under which data is categorised are comprised of energy inputs, raw material inputs, waste, discharge water, transport, land use, emissions to air, emissions to water, emissions to land use, and noise emissions.

2.4 Modelling the system

Every unit process is modelled with generic data sets and supplementary emission data. There are about 40 generic data sets. Some generic data sets are taken directly from Frischknecht and co-workers (1995). Other generic data sets are taken from different sources (Fritsche et al., 1994; Jungbluth, 1997; Kindler and Nikles, 1979; Schul et al., 1995), often in combination with the generic data of Frischknecht and co-workers (1995).

2.5 Criteria for initial inclusion of inputs and outputs

Ancillary materials contributing more than 5% of the cumulative energy demand of the unit process are included. Emissions of soil washing processes and of some other unit processes can/have to be added by the software user.

2.6 Data quality

The method uses a streamlined LCA. In the planning of a remedial action details of the machines (manufacturer of the machines, age of the machines, state of the machine, type of handling of the machine) are out of scope. Average data is utilised. Data of the unit processes are mainly from 1988 to 1996. Several assumptions in the data sources used go back before 1988. Most data belong to Western Europe, but some data is related to a global scale, as well (for example oil extraction). The unit process data is averaged if multiple published sources have been available.

The data variability is different for the unit processes. Some data of the unit processes (energy, water, ancillary materi-

als) are better by a factor of two. Other data is less precise. Most data of the unit processes is representative within a data precision by a factor two for the first half of the decade 1990 to 1995 for the technology in Germany and partially of Western Europe. The emission data has very different precisions (FINNVEDEN and LINDFORS, 1998). The polychlorinated dibenzodioxins (PCDD/F) are probably not more precise than by one order of magnitude.

3 Life Cycle Inventory Analysis

3.1 Unit processes

54 Unit processes are defined. Among these are 13 decontamination technologies, ten ensuring technologies, and 31 secondary technologies (construction, transports, air purification, water treatment).

The example Modellvorhaben Sinsheim includes the comparison of three remedial alternatives. The contaminated site of the former company Reinig in Sinsheim has an area of 20000 square meters. Mineral oil contaminates 530 cubic meters, polycyclic aromatics (PAH) 750 cubic meters, and chromium 530 cubic meters soil. Ground water is not polluted. It is assumed that three options perform the same functional unit. The site is remediated to decrease the risk level "Maßgebliches Risiko" to an accepted level ("4").

On-site ensuring means the excavation and on-site redumping of the contaminated soil. The second remedial option is the simple sealing of the surface by asphalt. The decontamination requires the excavation and three different treatments. 75 m^3 of contaminated concrete is included in the "on-site ensuring" option, but not in the other two options "soil sealing" and "decontamination". In the option "on-site ensuring", only 50% of the PAH contaminated soil is excavated. The other 50% of the PAH contaminated soil is under the clamp of the redeposited contaminated soil. The aggregated input data (for the unit processes) of the three options is described in Table 2.

3.2 Generic life cycle inventory data

42 generic life cycle inventory data sets are in the software tool. Single emissions can be added in some unit processes (for example air emissions in the unit process purification of discharge air).

3.3 Life cycle inventory table Modellvorhaben Sinsheim

The data in Table 3 are linked with the generic life cycle inventory data. Inventory data is calculated for the unit processes. The aggregated inventory is listed.

Table 2: Unit processes used in the Modellvorhaben Sinsheim case study

Unit process	On-site ensuring	Surface sealing	Decontamination
Soil washing – mobile installation			530 m^3, 50% refilled, 50% landfilled
Microbiological soil treatment – turning bed			530 m^3, 12 volume percent organic and inorganic structure improver each, 1 kg nutrients/(Mg soil)
Thermal treatment "Herne"			1350 Mg
Asphalt coating		20.000 m^2	
Processed soil materials	2730 m^3		265 m^3
Plastics, concrete polyvinylchloride (PVC), high density polyethylene (HDPE)	5600 m^2 fleece (HDPE), 1400 m^2 foil (HDPE), 200 m tube (ø 100 mm) (PVC), 6 m man-hole tube (concrete)		
Material transport on-site	1505 m^3		2518 m^3
Distribution by caterpillar	4310 m^3		2104 m^3
Excavation of soil	1505 m^3		1810 m^3
Soil preparation (sieving, breaking up)	75 m^3 (breaking up concrete)		
Mobilisation, Demobilisation	475 km, 15 arrivals	100 km, 8 arrivals	200 km, 12 arrivals
Transportation (truck)	122.200 Mg km total (1365 Mg km on-site)	289751 Mg km total (3622 Mg km on-site)	170.298 Mg km total (890 Mg km on-site)
Transportation (river ship)			1.800.000 Mg km
Transportation (car)	5000 km, 50 arrivals	6000 km, 30 arrivals	

HDPE = high density polyethylene, kg = kilogram; km = 1000 m; Mg = 1000 kg; PVC = polyvinylchloride

Table 3: Life cycle inventory table

Type	Inventory entry	Unit	On-site-ensuring	Soil sealing	Decontamination
1	Energy renewable	TJ	3.10E-02	8.28E-02	8.99E-02
1	Energy nuclear	TJ	1.82E-01	4.88E-01	4.99E-01
1	Energy fossil	TJ	1.25E+00	3.31E+01	5.13E+00
1	Cumulative energy demand	TJ	1.46E+00	3.37E+01	5.72E+00
2	Inert waste	kg	1.18E+04	1.81E+04	2.27E+04
2	Municipal waste	kg	6.91E+01	1.06E+02	4.92E+02
2	Waste contaminated site to landfill	kg	0.00E+00	0.00E+00	5.30E+05
2	Hazardous waste	kg	3.18E+03	1.97E+04	5.58E+05
2	Waste total	kg	1.51E+04	3.80E+04	5.66E+05
3	Truck transport road	Mg km	1.30E+05	1.56E+05	1.95E+05
3	Train transport	Mg km	5.89E+03	1.86E+04	3.01E+04
3	River ship transport	Mg km	3.33E+03	1.16E+04	1.84E+06
3	Car transport road	km	1.29E+04	1.51E+04	1.13E+04
4	Crude oil	kg	2.12E+04	6.81E+05	8.76E+04
4	Natural gas	kg	1.02E+03	2.57E+03	3.11E+03
4	Hard coal in soil	kg	6.04E+03	1.65E+04	2.37E+04
4	Lignite in soil	kg	7.66E+03	1.67E+04	3.71E+04
4	Oil gas	kg	8.96E+02	2.88E+04	3.71E+03
4	Gas from coal (methane)	kg	4.45E+01	1.21E+02	1.85E+02
4	Uranium in ore	kg	4.22E-01	1.14E+00	1.16E+00
4	Wood	kg	2.53E+02	4.42E+02	1.17E+03
4	Water	Mg	1.15E+03	6.07E+03	5.72E+03
5	Land cultivated	m^2 a	4.75E+04	1.80E+05	1.64E+04
5	Land built-up area	m^2 a	1.54E+04	4.67E+04	1.31E+04
5	Land total	m^2 a	6.29E+04	2.26E+05	2.96E+04
6	CO_2 Carbon dioxide	kg	6.54E+04	3.20E+05	3.62E+05
6	CO Carbon oxide	kg	2.14E+02	6.13E+02	6.76E+02
6	CN Cyanides	kg	4.27E-05	1.78E-04	2.16E-04
6	NO_x Nitrogen oxides	kg	6.50E+02	2.27E+03	1.91E+03
6	NH_3 Ammonia	kg	7.24E-02	1.73E-01	9.29E-01
6	N_2O Dinitrogen oxide	kg	1.75E+00	6.34E+00	5.40E+00
6	P and Phosphate as P	kg	6.32E-01	7.58E-01	9.09E-01
6	SO_2 Sulphur dioxide	kg	2.02E+02	1.95E+03	6.99E+02
6	H_2S Sulfane	kg	4.07E-02	1.38E-01	1.68E-01
6	HF Hydrogen fluoride	kg	2.88E-01	9.38E-01	7.14E-01
6	HCl Hydrogen chloride	kg	6.34E+01	7.75E+01	9.91E+01
6	Bromine	kg	3.13E+00	3.60E+00	4.48E+00
6	I Iodine	kg	1.09E-01	1.36E-01	1.62E-01
6	CH_4 Methane	kg	1.52E+02	2.71E+03	6.20E+02
6	Alkanes	kg	8.36E+00	2.25E+02	4.68E+01
6	Alkenes	kg	3.66E-01	6.24E+00	1.47E+00
6	Alkanoles	kg	3.82E-02	2.39E-01	1.23E-01
6	CH_2O Methanal	kg	1.14E-01	3.21E-01	1.77E+00
6	Alkane acids	kg	4.42E-02	2.23E-01	1.23E-01
6	C_6H_6 Benzene	kg	1.04E+00	5.53E+00	1.11E+00
6	BTX Aromatics	kg	7.82E-01	1.38E+01	3.72E+00
6	$C_{20}H_{12}$ Benzo[def]chrysene Benzo[a]pyrene	kg	8.79E-05	2.44E-04	3.58E-04
6	PAH Polycyclic aromatic hydrocarbons	kg	8.19E-04	3.28E-03	3.58E-03
6	Aromatics	kg	1.45E-02	4.30E-02	6.81E-02
6	C_6H_6O Phenol	kg	4.39E-05	1.96E-04	6.24E-03
6	NMVOC Nonmethane volatile organic compounds	kg	2.88E+02	5.25E+03	1.04E+03
6	C_2ClH_3 Chloroethene (Vinyl chloride)	kg	6.19E-02	1.83E-03	1.94E-02
6	PCDD/F Polychlorinated dibenzodioxines and -furans	kg	8.42E-10	3.32E-09	4.23E-09
6	$(CClH_2)_2$ 1.2-Dichloroethane	kg	1.08E-01	3.20E-03	3.39E-02
6	CF_4 Tetrafluoromethane	kg	4.23E-02	6.21E-02	8.44E-02
6	C_2F_6 Hexafluoroethane	kg	5.30E-03	7.77E-03	1.06E-02
6	$BrCF_3$ Bromotrifluoromethane 1301	kg	5.07E-03	1.63E-01	2.10E-02
6	Organics (aldehydes. ketones. alkines. ether)	kg	5.34E-02	1.47E-01	6.08E-02
6	Soot. diesel soot	kg	8.86E+00	2.81E+01	6.98E+01
6	Particles	kg	1.50E+02	6.40E+02	6.16E+02
6	As Arsenic	kg	2.99E-03	1.34E-02	7.14E-03
6	Be Beryllium	kg	3.91E-05	1.15E-04	6.49E-05
6	Cd Cadmium	kg	2.56E-03	2.36E-02	7.71E-03
6	Cr Chromium	kg	4.30E-03	2.38E-02	1.37E-02
6	Cu Copper	kg	4.48E-02	1.07E-01	1.26E+00
6	Hg Mercury	kg	7.62E-04	3.22E-03	3.33E-03
6	Pb Lead	kg	6.88E-02	1.52E-01	8.84E-02
6	U Uranium	kg	1.05E-04	3.17E-04	1.12E-04
6	Zn Zinc	kg	8.93E-01	1.14E+00	2.47E+00

Table 3 *cont'd*

Type	Inventory entry	Unit	On-site-ensuring	Soil sealing	Decontamination
6	Radiation	kBq	3.68E+07	9.88E+07	1.01E+08
7	Mineral oil (Alkanes)	kg	1.38E-01	4.42E+00	5.71E-01
7	C_6H_6 Benzene	kg	1.39E-01	4.43E+00	5.79E-01
7	BTX Aromatics	kg	2.51E-01	8.04E+00	1.04E+00
7	PAH Polycyclic aromatic hydrocarbons	kg	1.38E-02	4.43E-01	5.74E-02
7	Aromatic hydrocarbons	kg	6.39E-01	2.05E+01	2.65E+00
7	Phenols	kg	1.57E-01	4.80E+00	6.19E-01
7	$(CClH_2)_2$ 1.2-Dichloroethane	kg	5.41E-02	1.60E-03	1.70E-02
7	Chlorinated organics (CCl_2H_2. C_2Cl_3H. C_6ClH_5. solvents)	kg	4.68E-02	3.19E-02	1.90E-02
7	AOX Adsorbable halogenated organics	kg	3.74E-03	1.21E-01	1.47E-02
7	BSB5 Biologic oxygen demand 5 days	kg	1.01E-01	1.34E+00	3.80E-01
7	COD Chemical oxygen demand	kg	4.76E+00	2.42E+01	1.40E+01
7	Tributyltin	kg	1.69E-03	4.59E-02	6.88E-03
7	Organics (fats. acids. alkenes. ether. Hydrocarbons. DOC)	kg	2.54E+01	8.09E+02	1.05E+02
7	Al Aluminium	kg	9.86E+00	2.68E+01	3.83E+01
7	As Arsenic	kg	2.04E-02	8.04E-02	8.04E-02
7	Cd Cadmium	kg	1.70E-03	3.90E-02	6.76E-03
7	Cr(VI) Chromium(VI)	kg	2.03E-05	5.43E-05	4.95E-05
7	Cr Chromium	kg	1.09E-01	5.67E-01	4.34E-01
7	Cu Copper	kg	5.10E-02	1.96E-01	2.01E-01
7	Hg Mercury	kg	3.03E-05	3.62E-04	1.31E-04
7	Ni Nickel	kg	5.32E-02	2.36E-01	2.12E-01
7	Pb Lead	kg	7.82E-02	2.89E-01	3.26E-01
7	Se Selenium	kg	4.97E-02	1.60E-01	1.95E-01
7	Sn Tin	kg	1.36E-04	2.80E-04	7.32E-04
7	Zn Zinc	kg	1.18E-01	6.13E-01	4.78E-01
7	Acids as H^+	kg	6.10E-03	2.54E-02	3.08E-02
7	NH_3 Ammonia as N	kg	1.55E+00	2.83E+01	6.60E+00
7	NO_3 Nitrate	kg	8.66E-01	2.25E+01	3.74E+00
7	F Fluoride	kg	1.09E-01	7.49E-01	5.50E-01
7	CN^- Cyanide	kg	9.79E-03	1.61E-01	4.72E-02
7	Radiation	kBq	3.39E+05	9.24E+05	9.34E+05
8	Mineral oil	kg	5.47E-02	1.57E+00	2.31E-01
9	Noise emission time 108 dB(A)	h	8.82E+01	1.60E+02	8.95E+01
9	Noise emission time 114 dB(A)	h	3.00E+00	0.00E+00	0.00E+00

Type: 1 Energy, 2 Waste, 3 Transport, 4 Resource, 5 Land use, 6 Air, 7 Water, 8 Soil, 9 Noise;
Unit: Bq = Bequerel, g = gram, h = hour, k = kilo, M = Mega

4 Life Cycle Impact Assessment

4.1 Definition

The impact categories resources, land use, global warming, acidification, photo-oxidant formation, toxicity, odour, and noise have been chosen. The toxicity addresses to human toxicity (air emissions, water emissions) and to plant toxicity (soil emissions). Three categories (toxicity, noise, odour) address to the people living on or in the neighbourhood of the contaminated site. In the life cycle interpretation all impact categories and additionally waste and energy are regarded. The subcategory "waste contaminated site to landfill" is included to indicate the possible redeposition of the contaminated soil in a landfill. The energy (cumulative energy demand based on gross calorific values) is included in the interpretation because this value has usually more precision as most of the impact categories and because energy is partially well correlated with some impact categories (global warming, acidification). **Table 4** lists the impact categories and their category indicators.

Table 4: Impact categories, category indicators

Impact categories	Category indicator	References
Fossil resources	Depletion of fossil (energy) resources with removal from the environment	LINDFORS et al. (1995)
Water	Depletion of water resources with removal from the environment	same as in LCI
Land use	Land used	same as in LCI
Global warming	Radiative forcing	HOUGHTON et al. (1996)
Acidification	Total emission of possible acid	LINDFORS et al. (1995)
Photo-oxidant formation	Total emission of organics with potential to form ozone	HEIJUNGS et al. (1992)
Toxicity	Total emissions of toxic emissions	LFU
Odour	Total emissions of odorant gases	
Noise	Emission of sound which can be heard by men	

LFU: VON DER TRENCK and JARONI (1999), VON DER TRENCK et al. (1992, 1993, 1995), VON DER TRENCK and RUF, 1994

4.2 Toxicity characterisation factors

The characterisation factors are the reciprocal values of the "Prüfwerte" originally used in Baden-Württemberg for contaminated site risk assessment (VON DER TRENCK et al., 1992, 1993, 1995; VON DER TRENCK and RUF, 1994). This list has been complemented for substances in air (VON DER TRENCK and JARONI, 1999). The Prüfwerte consider primarily human toxicity (air and water). For soil separate Prüfwerte for man and plants exist. If separate Prüfwerte are available, the lowest one is taken for the calculation of the characterisation factor in the life cycle assessment. If the value for the plant toxicity is lower than the value for human toxicity than the characterisation factor is calculated from the Prüfwert based on the plant toxicity (worst case philosophy). **Table 5** lists the Prüfwerte Baden-Württemberg used in this project.

Table 5: Prüfwerte (P) Baden-Württemberg and characterisation factors toxicity (T)

Type	Inventory entry	Unit P	P	Unit T	T
6	CO_2 Carbon dioxide	$\mu g/m^3$	900000	km^3/kg	0.00000111
6	CO Carbon oxide	$\mu g/m^3$	10000	km^3/kg	0.0001
6	CN Cyanides	$\mu g/m^3$	100	km^3/kg	0.01
6	NO_x Nitrogen oxides	$\mu g/m^3$	50	km^3/kg	0.02
6	NH_3 Ammonia	$\mu g/m^3$	500	km^3/kg	0.002
6	N_2O Dinitrogen oxide	$\mu g/m^3$	6000	km^3/kg	0.000167
6	SO_2 Sulphur dioxide	$\mu g/m^3$	140	km^3/kg	0.00714
6	H2S Sulfane	$\mu g/m^3$	20	km^3/kg	0.05
6	HF Hydrogen fluoride	$\mu g/m^3$	0.2	km^3/kg	5
6	HCl Hydrogen chloride	$\mu g/m^3$	100	km^3/kg	0.1
6	Alkanes	$\mu g/m^3$	6000	km^3/kg	0.000167
6	CH_2O Methanal	$\mu g/m^3$	60	km^3/kg	0.0167
6	C_6H_6 Benzene	$\mu g/m^3$	1	km^3/kg	1
6	BTX Aromatics	$\mu g/m^3$	300	km^3/kg	0.00333
6	$C_{20}H_{12}$ Benzo[def]chrysene Benzo[a]pyrene	$\mu g/m^3$	0.0013	km^3/kg	769
6	PAH Polycyclic aromatic hydrocarbons	$\mu g/m^3$	0,012	km^3/kg	83.3
6	Aromatics	$\mu g/m^3$	600	km^3/kg	1.67
6	C_2ClH_3 Chloroethene (Vinyl chloride)	$\mu g/m^3$	0.02	km^3/kg	50
6	PCDD/F Polychlorinated dibenzodioxins and -furans	$\mu g/m^3$	7E-7	km^3/kg	1430000
6	$(CClH_2)_2$ 1,2-Dichloroethane	$\mu g/m^3$	0.03	km^3/kg	33.3
6	Chlorinated organics	$\mu g/m^3$	20	km^3/kg	0.05
6	Soot, diesel soot	$\mu g/m^3$	1	km^3/kg	1
6	Particles	$\mu g/m^3$	75	km^3/kg	0.0133
6	As Arsenic	$\mu g/m^3$	0.003	km^3/kg	333
6	Cd Cadmium	$\mu g/m^3$	0.001	km^3/kg	1000
6	Hg Mercury	$\mu g/m^3$	0.18	km^3/kg	5.56
6	Pb Lead	$\mu g/m^3$	1.5	km^3/kg	0.667
6	Zn Zinc	$\mu g/m^3$	50	km^3/kg	0.02
7	Mineral oil (Alkanes)	mg/m^3	50	$10^6\ m^3/kg$	0.02
7	C_6H_6 Benzene	mg/m^3	1	$10^6\ m^3/kg$	1
7	BTX Aromatics	mg/m^3	10	$10^6\ m^3/kg$	0.1
7	PAH Polycyclic aromatic hydrocarbons	mg/m^3	0.15	$10^6\ m^3/kg$	6.67
7	Aromatic hydrocarbons	mg/m^3	10	$10^6\ m^3/kg$	0.1
7	Phenols	mg/m^3	30	$10^6\ m^3/kg$	0.0333
7	$(CClH_2)_2$ 1,2-Dichloroethane	mg/m^3	3	$10^6\ m^3/kg$	0.333
7	Chlorinated organics (CCl_2H_2, C_2Cl_3H, C_6ClH_5, solvents)	mg/m^3	10	$10^6\ m^3/kg$	0.1
7	Organics (fats, acids, alkenes, ether, hydrocarbons, DOC)	mg/m^3	50	$10^6\ m^3/kg$	0.02
7	Al Aluminium	mg/m^3	150	$10^6\ m^3/kg$	0.00667
7	As Arsenic	mg/m^3	10	$10^6\ m^3/kg$	0.1
7	Cd Cadmium	mg/m^3	3	$10^6\ m^3/kg$	0.333
7	Cr(VI) Chromium(VI)	mg/m^3	8	$10^6\ m^3/kg$	0.125
7	Cr Chromium	mg/m^3	40	$10^6\ m^3/kg$	0.025
7	Cu Copper	mg/m^3	100	$10^6\ m^3/kg$	0.01
7	Hg Mercury	mg/m^3	0.7	$10^6\ m^3/kg$	1.43
7	Ni Nickel	mg/m^3	20	$10^6\ m^3/kg$	0.05
7	Pb Lead	mg/m^3	10	$10^6\ m^3/kg$	0.1
7	Se Selenium	mg/m^3	8	$10^6\ m^3/kg$	0.125
7	Sn Tin	mg/m^3	10	$10^6\ m^3/kg$	0.1
7	Zn Zinc	mg/m^3	1500	$10^6\ m^3/kg$	0.000667
7	NH_3 Ammonia as N	mg/m^3	700	$10^6\ m^3/kg$	0.00143
7	NO_3^- Nitrate	mg/m^3	50000	$10^6\ m^3/kg$	0.00002
7	F^- Fluoride	mg/m^3	750	$10^6\ m^3/kg$	0.00133
7	CN^- Cyanide	mg/m^3	40	$10^6\ m^3/kg$	0.025
8	Mineral oil	mg/kg	400	kg/kg	2500

Type: 6 Air, 7 Water, 8 Soil

4.3 Odour

The recorded minimum odour threshold values (OTV) from five references are taken as characterisation factors (→ *Table 6*). The characterisation factor is the reciprocal value of the odour threshold value.

Table 6: Odour threshold values (OTV)

Inventory entry	OTV, Minimum, mg/m³	OTV, Maximum, mg/m³	Reference
SO_2 Sulphur dioxide	**0.3**	2.5	2
NO_x Nitrogen oxides as NO_2	**0.2**	0.8	2
HCl Hydrogen chloride	**7**	15	2
NH_3 Ammonia	**0.028**	50	1; 2; 3
H_2S Sulfane	**0.00043**	0.15	1; 2; 3
CH_2O Methanal	**0.06**	2.7	1; 2; 3; 5
C_6H_6 Benzene	**0.52**	180	1; 4
C_6H_6O Phenol	**0.021**	2.1	1; 4

[1] VERSCHUEREN (1977); [2] KÜHN BIRETT (1997); [3] HEIJUNGS et al. (1992); [4] WASHBURN (1926); [5] WITTHAUER et al. (1993)

5 Life Cycle Interpretation

5.1 Interpretation of inventory and impact assessment

The life cycle assessment is interpreted calculating disadvantage factors, the parameters of cumulative energy demand, waste and all impact categories. The disadvantage factor is the quotient of the higher and the lower value. The disadvantage factor is always equal to one or larger. Quotients smaller than two are rounded to one. Quotients larger than two are rounded to by one digit. Because of the uncertainty of the results of the life cycle inventory table and the category indicators a more precise calculation of the disadvantage factors is not justified.

For one parameter, the disadvantage factor larger than one is attributed to the remediation option with the higher parameter value. Further aggregation of the single disadvantage factors to one overall score is not allowed.

In the software, the disadvantage factors for two remediation options are displayed in a table (disadvantage factor table). In case of a disadvantage factor table with disadvantage factors for parameters based on the near emissions, the method includes a further evaluation of the near emission range regarding the severity of the nuisances to the people living in the near emission range. In all cases with an ambiguous disadvantage factor table the user of the method has the possibility to improve one option in order to achieve an unambiguous result.

5.2 Disadvantage factors

Table 7 lists the parameter values which are used to calculate the disadvantage factors in *Table 8*.

In Table 8, a disadvantage factor is attributed to each parameter. The option for on-site ensuring has the disadvantage factor 1 for all but one parameter. The parameter "noise immission

Table 7: Life cycle interpretation parameters

Impact categories and energy and waste	Unit	On-site ensuring	Soil sealing	Decontamination
Cumulative energy demand	TJ	1.46	33.7	5.72
Waste total	Mg	15.1	38	566
Waste from contaminated site to landfill	Mg			530
Fossil resources	kg/a	604	17900	2490
Water	m³	1150	6070	5720
Land use	m² a	62900	226000	29600
Global warming	kg CO_2	69500	379000	377000
Acidification	kg SO_2	714	3610	2130
Photo-oxidant formation	kg Ethene	125	2310	462
Toxicity air – remote emissions	km³	34.4	115	130
Toxicity water	10^6 m³	0.95	27	3.83
Toxicity soil	kg	140	3940	580
Odour – remote emissions	km³	3.7	17.8	11.8
Toxicity air – near emissions	km³	2.56	2.82	3.94
Odour – near emissions	km³	0.331	0.363	0.509
Noise immission 60 dB(A)	h	88.25	160	89.5
Noise immission 66 dB(A)	h	3		

dB(A) deciBel(A), h hour, TJ Terajoule

Table 8: Life cycle interpretation: disadvantage factors

Impact categories and energy and waste	On-site ensuring	Soil sealing	Decontamination
Cumulative energy demand	1	20	4
Waste total	1	2	40
Waste from contaminated site to landfill			!
Fossil resources	1	30	4
Water	1	5	5
Land	2	7	1
Global warming	1	5	5
Acidification	1	5	3
Photo-oxidant formation	1	20	4
Toxicity air – remote emissions	1	3	4
Toxicity water	1	30	4
Toxicity soil	1	30	4
Odour – remote emissions	1	5	3
Toxicity air – near emissions	1	1	1
Odour – near emissions	1	1	1
Noise immission 60 dB(A)	1	1	1
Noise immission 66 dB(A)	!		
Sum of disadvantage factors	NOT ALLOWED		

66 dB(A)" is only relevant in the option "on-site ensuring" because the concrete breaking-up machine is used only in this option. The disadvantage factor is indicated as "!". The soil washing in option "decontamination" causes waste which is soil from the contaminated site. Soil from the contaminated site is not landfilled in the two other options. Therefore, the disadvantage factor is "!" for the option "decontamination".

According to *Table 8*, and neglecting the parameter "noise immission 66 dB(A), the option soil sealing is worse than on-site ensuring. The land use is more disadvantageous in on-site ensuring than in decontamination. This is due to the use of new soil to fill the excavation in the on-site ensuring option.

The remediation planner can improve the on-site ensuring alternative by using used soil instead of new soil to fill the excavations. No environmental burden is associated with the used soil. This Allocation rule is often utilised for used products (recycled products) (Klöpffer, 1996). In this case the category indicator result for land use is reduced by 30500 m^2 a for the on-site ensuring option and 5600 m^2 a (replacing soil loss in soil washing) for the decontamination option. The category indicator results are then 32500 m^2 a (improved on-site ensuring option) and 23900 m^2 a (decontamination option with the same change of premises as on-site ensuring). The difference is less than a factor of two. Therefore, the disadvantage factor for the land use is one (no significant difference). The improvement assessment also causes changes in the other category indicator results and disadvantage factors, but the overall ranking is not changed except for land use.

The decontamination is worse than the soil sealing concerning the waste parameters. In energy, fossil resources, photo-oxidant formation, toxicity water and toxicity soil, however, the option soil sealing is worse than the option decontamination.

5.3 Sensitivity analysis

Usually, parameter differences resulting in a rounded disadvantage factor 1 are not used to justify a ranking in the life cycle interpretation. In a few cases this can be reasonable. This is the case if the two compared options use the same unit processes, but one option has higher or equal values than the other option in all unit processes. One example for the case study soil vapour extraction is given by Bender and co-workers (1998).

The sensitivity of the LCA interpretation related to the human toxicity air category relating to diesel soot is discussed. The toxicity air for remote and near emissions is governed by diesel soot and a few other substances. The near emissions result mainly from diesel engines. The "Umweltgutachten" (1994) attributed the human toxicity air potential of diesel engines mainly to diesel soot. This is in accordance with the findings in this paper.

The diesel soot emission variability of diesel engines (scenarios 1, 2 and 3) and the characterisation factor variability (scenarios 1, 4 and 5) are evaluated in respect to the LCA interpretation results.

The scenarios 2 (clean diesel) and 3 (dirty diesel) change only the direct diesel soot emission of the machines used directly (dredger, truck, ship), not the diesel soot emission of diesel engines used to make the machines and fuels (→ *Table 9*).

Table 9: Scenario definition

Scenario number	Scenario name	Diesel soot emission, g/(kg Diesel)	Characterisation factor diesel soot, km^3/(kg diesel soot)
1	Standard	2.5 (ship); 1.2 (all other)	1
2	Clean diesel	0	1
3	Dirty diesel	10	1
4	Harmless soot	2.5 (ship); 1.2 (all other)	0
5	Harmful soot	2.5 (ship); 1.2 (all other)	10

Table 10: Inventory table data: diesel soot in kilogram

Near/Remote emissions	Case	Scenario 1, 4, 5	Scenario 2	Scenario 3
Near	On-site ensuring	1.24	0.00068	10.4
Remote	On-site ensuring	7.62	1.09	55.5
Near	Surface sealing	1.36	0.00041	11.3
Remote	Surface sealing	26.7	19.3	81.3
Near	Decontamination	1.91	0	16
Remote	Decontamination	67.8	4.47	298

The inventory data for diesel soot varies sometimes more than one order of magnitude for the different scenarios (→ *Table 10*).

The variability of the indicator results (→ *Table 11*) concerning the scenarios is not more than one order of magnitude. Therefore, the variability of the indicator results is less than the one of the inventory results concerned with diesel soot because the diesel soot effect is diluted by the other toxic emissions. The other toxic emissions in the inventory table are the same for every scenario.

The toxic near emissions come mostly from machines using diesel fuel. The diesel fuel consumptions (without the lorries and cars) are similar for the three remediation options (1000 kg to 1500 kg Diesel). Therefore, the disadvantage factors for the near emissions concerned with toxicity are independent of the scenario. The disadvantage factors depend in many remediation cases from the diesel fuel consumption. Remediations with a stripping of volatile substances can show other dependencies.

Table 11: Impact category toxicity air: indicator results in km³

Near/Remote emissions	Case	Scenario	Diesel soot	Other	Total
Near	Decontamination	1 Standard	1.91	2.03	3.94
Near	Decontamination	2 Clean diesel	0	2.03	2.03
Near	Decontamination	3 Dirty diesel	16	2.03	18
Near	Decontamination	4 Harmless soot	0	2.03	2.03
Near	Decontamination	5 Harmful soot	19.1	2.03	21.1
Remote	Decontamination	1 Standard	69.8	64.2	134
Remote	Decontamination	2 Clean diesel	4.47	64.2	68.8
Remote	Decontamination	3 Dirty diesel	314	64.2	379
Remote	Decontamination	4 Harmless soot	0	64.2	64.2
Remote	Decontamination	5 Harmful soot	698	64.2	762
Near	On-site ensuring	1 Standard	1.24	1.32	2.56
Near	On-site ensuring	2 Clean diesel	0	1.32	1.32
Near	On-site ensuring	3 Dirty diesel	10.4	1.32	11.7
Near	On-site ensuring	4 Harmless soot	0	1.32	1.32
Near	On-site ensuring	5 Harmful soot	12.4	1.32	13.7
Remote	On-site ensuring	1 Standard	7.62	26.7	34.4
Remote	On-site ensuring	2 Clean diesel	1.09	26.7	27.9
Remote	On-site ensuring	3 Dirty diesel	55.5	26.7	82.3
Remote	On-site ensuring	4 Harmless soot	0	26.7	26.7
Remote	On-site ensuring	5 Harmful soot	76.2	26.7	103
Near	Surface sealing	1 Standard	1.36	1.46	2.82
Near	Surface sealing	2 Clean diesel	0	1.46	1.46
Near	Surface sealing	3 Dirty diesel	11.3	1.46	12.8
Near	Surface sealing	4 Harmless soot	0	1.46	1.46
Near	Surface sealing	5 Harmful soot	13.6	1.46	15.1
Remote	Surface sealing	1 Standard	26.7	87.9	115
Remote	Surface sealing	2 Clean diesel	19.3	87.9	107
Remote	Surface sealing	3 Dirty diesel	81.3	87.9	169
Remote	Surface sealing	4 Harmless soot	0	87.9	87.9
Remote	Surface sealing	5 Harmful soot	267	87.9	355

Table 12: Disadvantage factors for impact category toxicity

Scenario	Emissions	On-site ensuring	Surface sealing	Decontamination
1 Standard	remote	1	3	4
2 Clean diesel	remote	1	4	2
3 Dirty diesel	remote	1	2	4
4 Harmless soot	remote	1	3	2
5 Harmful soot	remote	1	3	7
1 Standard	near	1	1	1
2 Clean diesel	near	1	1	1
3 Dirty diesel	near	1	1	1
4 Harmless soot	near	1	1	1
5 Harmful soot	near	1	1	1

The ranking between on-site ensuring and surface sealing, and between on-site ensuring and decontamination is independent of the five scenarios considered. The scenarios standard (1), clean diesel (2), and harmless soot (4) demonstrate no difference between surface sealing and decontamination. All disadvantage factors are one if only these two remediation options are considered. Only the dirty diesel scenario (3) and the harmful soot scenario (5) exhibit a disadvantage for the toxicity based on remote emissions. The diesel soot emissions in the remediation option decontamination are mainly caused by the ship transport of the contaminated soil to the thermal treatment plant. In the standard scenario (1) the remote diesel soot emissions for decontamination are a factor of two to eight larger than for the two other options on-site ensuring and surface sealing. The dilution effect within the impact category by the other toxic emissions can be neglected in the dirty diesel and harmful diesel scenario.

For the evaluated remediation options, the overall result (ranking of the remediation options) of the life cycle interpretation is independent of the diesel soot emission data (inventory) and the characterisation factor of diesel soot.

6 Improvement Assessment

The improvement assessment is used to transform an ambiguous disadvantage factor table into an unambiguous one. The remediation planner is encouraged to try an improvement assessment of remediation options in order to reach an unambiguous disadvantage factor table. One example for an improvement assessment is given for the impact category land use (*section 5.2*).

The improvement assessment of the on-site ensuring option (used soil) results in a lower indicator result (land use). The user can try to improve one option by making changes in his remediation plan without changing the functional unit for this option. The improvement assessment will not always lead to an unambiguous result.

7 Synopsis of Primary and Secondary Impacts

Comparisons can be made within the life cycle assessment. Based on the disadvantage factor table, the user can often make a ranking between his (improved) options.

The next step is to compare the results of the LCA (secondary impacts) with the results of the risk assessment (primary impacts). The risk assessment is performed outside of this method. The risk assessment gives information about the risk before and after the remediation or the area of the contaminated site (before the remediation). For all options to be compared with this method these risk figures are the same.

Other primary impacts are the area of different land quality (housing, industry, ...) after the remediation, the area and volume of polluted groundwater after and before the remediation, and the remediation time (→ *Table 13*).

According to Table 13, the soil sealing has unfavourable primary impacts compared to the on-site ensuring option. Decontamination is more favourable as the on-site ensuring alternative regarding the area of the high quality land if the time of the remediation is neglected. These two differences between the three options have been ignored in the functional unit definition of the LCA. But they are not lost for the final decision making. Neither the LCA result nor the primary data is aggregated to one single score. The tool described here gives the information of what secondary and what primary data has to be considered for the decision making. How to make the decision is not regulated by this method. The different character of the secondary impacts (burdens and potential impacts) and the primary data (predicted information about the risk equivalence of the remedial options, the quality of the remediated land and the duration of the remediation) is no obstacle for the decision making.

The user has now to make a decision about his ranking of the remedial alternatives. He will write down the pros and cons of his decision. The decision might be: The soil sealing option is unfavourable in respect to the primary and secondary impacts. If the area of 1500 m^2 ensured land is ne-

Table 13: Some of the primary impacts Modellvorhaben Sinsheim

Remediation options		On-site ensuring	Soil sealing	Decontamination
Area balance	Housing area, m^2	18500		20000
	Ensured area, m^2	1500	20000	
Time of remediation, months		1	1	25

glected the decontamination is unfavourable to the on-site ensuring because of the secondary impacts and the time of the remediation. If the user is setting other priorities (higher weighting of the area of land) the ranking between decontamination and on-site ensuring can then be altered, but not the ranking between the soil sealing and the other two options.

The tool described here stops at this point. But the final decision making (which is performed in Baden-Württemberg in a panel) requires the consideration of additional aspects (financial, legal and technical).

8 Conclusions

8.1 Software tool

The software tool is designed for remediation planners. The software tool is suitable for most remediation plans. It allows comparisons of different remediation options leading to the same risk level after the remediation. The tool supplements the environmental information gained by a risk assessment with information about secondary impacts.

In the future, the software tool will require updates of the generic data sets, unit processes, characterisation factors, and life cycle impact assessment definition.

8.2 Reporting

The software tool allows the user to export data of the used generic data, unit processes, life cycle inventory tables of the unit processes and the whole remediation option, the life cycle impact assessment of the whole option or of parts of it, the disadvantage factor table, and the table for the primary impacts. The user has thus the possibility to document his decision making in a transparent way.

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9 References

Beinat, E.; van Drunen, M. A.; Janssen, R.; Njiboer, M. H.; Kohlenbrander, J. G. M.; Okx, J. P. (1997): The REC decision support system for comparing soil remediation options. A methodology based on risk reduction, environmental merit and costs. Civieltechnisch Centrum Uitvoering Research en Regelgeving (CUR), Nederlands Onderzoeksprogramma biotechnologische In-situ Sanering (NOBIS), Büchnerweg 1, Postbus 420, 2800 AK Gouda, Netherlands

Bender, A.; Volkwein, S.; Battermann, G.; Klöpffer, W.; Hurtig, H.-W.; Kohler, W. (1998): Life cycle assessment for remedial action techniques: methodology and application. ConSoil '98, Sixth international FZK/TNO Conference on contaminated soil. Thomas Telford, London. pp. 367-376

Diamond, M. (1998): Life cycle approaches to contaminated site remediation: generic assessments and development of toxicity approaches. Environ. Tox. Chem., submitted

Finnveden, G.; Lindfors, L.-G. (1998): Data quality of life cycle inventory data: Rules of thumb. Int. J. LCA 3, 65-66

Frischknecht, R.; Hofstetter, P., Knoepfel, I.; Dones, R.; Zollinger, E. (1995): Ökoinventare für Energiesysteme. Bundesamt für Energiewirtschaft, Bern. 2. Auflage. ENET, Postfach 130, 3000 Bern 16, Switzerland

Fritsche, U. R.; Leuchtner, J.; Matthes; Felix C.; Rausch, L.; Simon, K.-H. (1994): Umweltwirkungsanalyse von Energiesystemen: Gesamt-Emissions-Modell Integrierter Systeme (GEMIS). Version 2.1. Darmstadt. Öko-Institut, Büro Darmstadt, Bunsenstr. 14, 64293 Darmstadt. Editor Hessisches Ministerium für Wirtschaft und Technik, Referat Öffentlichkeitsarbeit, Kaiser-Friedrich-Ring 75, Wiesbaden, Germany. pp. 1-226

Heijungs, R.; Guinée, J. B.; Udo de Haes, H. A.; Wegener Sleeswijk, A.; Ansems, A. M. M.; Eggels, P. G.; van Duin, R.; de Goede, H. P. (1992): Environmental life cycle assessment of products. Guide – October 1992, 1-96. Backgrounds, pp. 1-130. Centre of Environmental Science, Leiden. ISBN 90-5191-064-9

Houghton, J. T.; Meira Filho, L. G.; Callander, B. A.; Harris, N.; Kattenberg, A.; Maskell, K. (Editors) (1996): Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on climate Change. Cambridge University Press. pp. 1-572

Joziasse, J.; Bakker, T.; Eggels, P. G. (1998): Decision support system for treatment of dredged sediments. ConSoil '98, Sixth international FZK/TNO Conference on contaminated soil. Thomas Telford, London. pp. 1193-1194

Jungbluth, N. (1997): Life-cycle-assessment for stoves and ovens. UNS Working Paper No. 16. pp. 1-47. Umweltnatur- und Umweltsozialwissenschaften, ETH Zürich, Universitätsstrasse 33, 8006 Zürich, Switzerland

Kindler, H.; Nikles, A. (1979): Energiebedarf bei der Herstellung und Verarbeitung von Kunststoffen. Chemie-Ingenieur Technik 51, 1125-1127

Kühn Birett (1997): Merkblätter Gefährliche Arbeitsstoffe 103. Ergänzungslieferung. Ecomed, Landsberg

Lindfors, L.-G.; Christiansen, K.; Hoffman, L.; Virtanen, Y.; Juntilla, V.; Hanssen, O.-J.: Ronning, Anne; Ekvall, T.; Finnveden, G. (1995): Nordic Guidelines on Life-Cycle Assessment. Nord 1995:20. ISBN 92 - 9120 692 X. pp. 1-222

Njiboer, M. H., Schelwald-van der Kley, A. J. M. (1998): Comparison of remediation technologies. Outcome of questionnaire and overview of developments. NICOLE. The Network for Industrially Contaminated Land in Europe. Tauw Milieu bv, Handelskade 11, Postbus 133, 7400 AC Deventer, Netherlands

Schul, W.; Hirsinger, F.; Schick, K.-P. (1995): A life-cycle inventory for the production of detergent range alcohol ethoxylates in Europe. Tenside Surf. Det. 32, 171-192

Umweltgutachten (1994): Der Rat von Sachverständigen für Umweltfragen (Editor): Umweltgutachten 1994. Metzler-Poeschel, Stuttgart, pp. 1-375

Umweltministerium (1987): Altlasten-Handbuch. Teil II. Untersuchungsgrundlagen. Ministerium für Ernährung, Landwirtschaft, Umwelt und Forsten Baden-Württemberg. Landesanstalt für Umweltschutz Baden-Württemberg, Griesbachstr. 1, 76157 Karlsruhe

Verschueren, K. (1977): Handbook of environmental data on organic chemicals. Van Nostrand Reinhold, New York, pp. 1-659

Volkwein, S.; Bender, A.; Klöpffer, W.; Hurtig, H.-W.; Battermann, G.; Kohler, W. (1998): Life cycle assessment method for remediation of contaminated sites. ConSoil '98, Sixth International FZK/TNO Conference on Contaminated Soil. Thomas Telford, London. pp. 1069-1070

Volkwein, S.; Klöpffer, W.; Hurtig, H.-W. (1997): Umweltbilanz von Altlastensanierungsverfahren. Proceedings "Ökobilanzen – Trends und Perspektiven". Working group "Ökobilanzen" of the Gesellschaft Deutscher Chemiker (Fachgruppe Ökologische Chemie). In the DECHEMA building in Frankfurt am Main, Germany. 26 June 1997

von der Trenck, K. T.; Jaroni, H. (1999): Vergleichende Bewertung von Umweltschadstoffen anhand von Risiko-Kennlinien. In: Rippen (Editor): Handbuch Umweltchemikalien. ecomed, Landsberg. Ergänzungslieferung, in press

von der Trenck, K. T.; Ruf, J. (1994): Grundlagen der konzentrationsbezogenen Bewertung anhand von Risiko-Kennlinien. In: Trägerverein des Instituts für wassergefährdende Stoffe e. V. an der Technischen Universität Berlin (Editor): Grundwassersanierung 1994. Rechtspraxis – Bewertungsgrundlagen – Kommunale Aufgaben – Praxisbeispiele, Berlin, 23. - 24.2.1994. IWS-Schriftenreihe Erich Schmidt Verlag, Volume 19, 1

von der Trenck, K. T.; Ruf, J.; Dieter, H. H. (1992): Integriertes

Risikomanagement am Beispiel Altlasten. In: FIEDLER, H.; DEMUTH, R.; LOB, R. E.; HUTZINGER, O. (Editors): Ecoinforma '92, Vol. 3, Bayreuth, pp. 279-293

VON DER TRENCK, K. T.; RUF, J.; DIETER, H. H. (1993): Zusammenführung von Altlastenbewertung und Sanierungszielfindung. UWSF – Z. Umweltchem. Ökotox. 5, 135-144

VON DER TRENCK, K. T.; RUF, J.; FLITTNER, M. (1994): Guide values for dealing with contaminated sites in Baden-Württemberg. Environ. Sci. Poll. Res. (Report on Regulatory Advances), 1, 253-261

VON DER TRENCK, K. T.; RUF, J.; JARONI, H. (1995): Orientierungswerte für umweltrelevante Schadstoffe in Rüstungsaltlasten. In: Rippen (Ed.): Handbuch Umweltchemikalien. ecomed, Landsberg. 28. Ergänzungslieferung 101-153

WASHBURN, E. W. (1926): International critical tables of numerical data, physics, chemistry and technology. National Research Council. USA. McGraw-Hill Book company, New York. p. 360

WITTHAUER, J.; H.; HORN, W.; BISCHOF (1993): Raumluftqualität. Belastung, Bewertung, Beeinflussung. Verlag c. f. Müller, Karlsruhe. pp. 1-296

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Conference Reports

Third euroMat Industry Workshop: Efficient Development of Sustainable Products

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Organized by the Department of Waste Minimization and Recycling of the Technical University Berlin, the 3rd euroMat Industry Workshop took place on April 27, 1999. Headed by Prof. Dr.-Ing. Günter Fleischer, the workshop focused on computer-aided material selection in the context of the Design for Environment (DfE).

Within the framework of a project commissioned by the German Federal Ministry for Research and Education, an interdisciplinary research team developed the tool euroMat. euroMat is a comprehensive material-selection tool enabling the designer to select the best possible materials or material combinations, as well as the corresponding manufacturing and recycling processes. It realizes a concurrent engineering approach and includes an assessment of the technological feasibility of materials, as well as an assessment of recycling quality, life cycle costs, work environment, risks involved, and environmental burdens from cradle-to-grave.

The environmental assessment is an adaptable iterative approach based upon the Life Cycle Assessment (LCA) framework according to ISO 14040 to 14043. This Iterative Screening LCA starts with a screening for hot-spots and ends with a detailed quantitative assessment (for further information see FLEISCHER and SCHMIDT, 1997 [1]).

Aside from the Technical University Berlin (head of project: Prof. Dr.-Ing. Günter Fleischer), the C.A.U. GmbH, the Fraunhofer Institutes ICT and IPT, the IKV of the RWTH Aachen, and the BTU Cottbus have also been involved in the development of the methodological foundations.

In order to implement euroMat as a software-based tool, the project team was expanded in 1998 to include the software engineering firm CAMTEC Software GmbH, as well as the four product developing companies Ford Werke AG, MAN Technologie AG, P&D Systemtechnik GmbH, and Sachsenring Entwicklungsgesellschaft mbH. This fruitful cooperation ensures the development of a powerful and industry oriented DfE tool.

At the beginning of the workshop the basic methodological foundations, the achieved results, and the current state of the software tool were presented to the representatives of 15 companies. The following discussion was enriched by a presentation by Ulrich Golüke from the Scenario Unit of the World Business Council for Sustainable Development. He pointed out concisely why sustainable development and material selection are essential challenges for industrial companies. The presentation offered ideas on how theses challenges could be turned into competitive advantages for strategically thinking companies.

In the second part of the workshop, the following issues were elaborated and discussed in separate working groups:

- 'euroMat - added value for the designer', focusing on the question "What are the conditions for the implementation of euroMat within the industrial design process?"
- 'data supply by the euroMat data bases' focusing on the question "What are the conditions whereby data providers as well as data users can benefit from euroMat?"

It became evident that the simple handling and documentation of the software, comprehensive training, the supply of extensive inventory data concerning material properties and process data, easy updating procedures, as well as the embedding of euroMat in existing software systems for product development within a company, are crucial for the successful industrial application.

The workshop ended with the conclusion that euroMat is a big step forward in the development of powerful DfE tools due to its methodological approach. The composition of the project team and the information exchange with many industry branches ensures the generation of a tool for the practitioner that can be tailored to specific design applications.

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For further information on euroMat, on the opportunities for cooperation with the project team, as well as for the future implementation of euroMat within your organization, please contact:

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[1] FLEISCHER, G.; SCHMIDT, W.-P.: Iterative Screening LCA in an Eco-design tool. Int. J. LCA (1997) 2, No. 1, pp. 20-24